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Circumferential Measurement of Anulus Deviation After Laser Nucleotomy

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Background and Objective: **Former studies investigated only the intradiscal pressure after laser nucleotomy. As the outer anulus causes compression of neural structures, the present in vitro study was performed to investigate the circumferential pressure conditions of the outer posterolateral anulus following laser nucleotomy.**
Study Design, Materials and Methods: **Laser nucleotomy was performed using a Hol:YAG laser (14 Watt, total energy applied 10kJ). Stiffness of the intervertebral disc and deviation of the posteriolateral portion of the disc under axial pressure were investigated. The forces observed during external deformation of the anulus were measured by stain gauges and recorded by a data logger. Measurements were taken at 4.8 and 10 kJ. The maximum axial load was 400 Newton.**
Results: **We found a preoperatively reduced external deviation within the punctured area after positioning the laser probe. Postoperatively, the posteriolateral parts of the disc showed a relatively increased external deviation due to reduced stiffness whereas the anterior parts remained unchanged. Stiffness of the disc decreased with increasing total energy applied.**
Conclusions: **Puncture of the intervertebral disc for laser nucleotomy should be performed on the side of the prolapse. Due to the reduced stiffness peak pressure loads on the protrusion site might be distributed over the whole disc. The linear negative correlation observed between energy and stiffness suggests a good therapeutic correlation with laser treatment. Lasers Surg Med 20:77–83, 1997**

Key words: Hol:YAG laser; intervertebral disc; pressure measurement

INTRODUCTION

The first paper on percutaneous laser nucleotomy was published by Choy in 1987 [1]. Since then this method has become a well-established technique for the treatment of protruded intervertebral discs [2–8].

Up to now, experimental investigations mainly measured the ablation rates of the different laser systems used, the temperature of intervertebral tissue during ablation, and intradiscal pressures before and after laser treatment of the intervertebral disc [9–17].

So far however, no study has been published on the biomechanics of the external deviation of the anulus which is responsible for compression of the adjacent neural structures. This is the first study to describe the influence of pressure conditions and external deviation on the anulus treated by laser nucleotomy.

MATERIALS

Laser

We used a 2.1 μm high power Hol:YAG laser (Coherent, Palo Alto, CA). Ablation was per-

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formed at an energy of 1.4 Joule and at a frequency of 10 Hz according to the instructions for clinical laser nucleotomies [6,7]. We used the lasekit instrumentation (Clarus, Minneapolis, USA) which disposes not only of an endoscopic device but also of two different channels allowing continuous rinsing and suction during ablation. Rinsing is performed at a flow of 10 ml per minute (pump type, Coherent). The intervertebral disc is punctured with the trokar contained in the set and the laser fiber is positioned in the posterolateral space. To achieve reproducible conditions, the position of the fiber remained unchanged during ablation of the nucleus. Ablation of the intervertebral discs was performed under continuous rinsing with physiological saline and simultaneous suction. The total energy applied was of 10 kJ, measurements being taken at 4.8 and 10 kJ, respectively.

For measurement we used 10 human cadaver intervertebral discs of the lumbar spine investigated within 48 hours post mortem. The specimens were stored at −4°C and investigated after 6–8 hours of storage at room temperature. The specimens were dissected from the adjacent soft tissue up to the longitudinal ligament as well as from processus transversus, processus spinosus, and pedicles. We used intervertebral discs which macroscopically seemed intact and stable. The adjacent vertebral bodies were resected by an oscillating saw in such a way that the two cutting planes were parallel and normal to the Z-axis.

Bone cement (Sulfix®, Winterthur, Switzerland) was added to ensure the axial direction of force after fixing the prepared intervertebral discs between two claw plates. The segments measured consisted of two adjacent vertebral bodies with one intervertebral disc in between. The experimental set-up consisted of a loading device for the exertion of an immediate axial deformation force (Fig. 1). The axial forces were measured by an integrated measurement device connected to a Newton-meter. The vertebral bodies were fixed with two claw plates adjustable in all three dimensions to avoid shearing forces. Axial shift was introduced via a small thread (1 turn = 0.5 mm) and steered laterally via a gear motor (Bosch, Germany). External dislocation of the intervertebral disc was measured in μm positive value. Internal dislocation of the intervertebral disc was determined in μm as the negative value of internal deviation. In all cases, the dislocations of the intervertebral disc was compared to the unloaded starting position. The forces observed at external deformation of the anulus were measured by stain gauges fitted with elongation measurement strips with sensors measuring deformation being connected to elastic spring bars. Dislocation of the elongation measurement strips was measured with an accuracy of 1 μm. By a magnetic rack it was possible to fix the sensors at variable height. The data measured by the elongation measurement strips were continuously recorded by a data logger (type Hordin, Schlumberger) and subsequently evaluated by a table calculation program (Technical University Vienna).

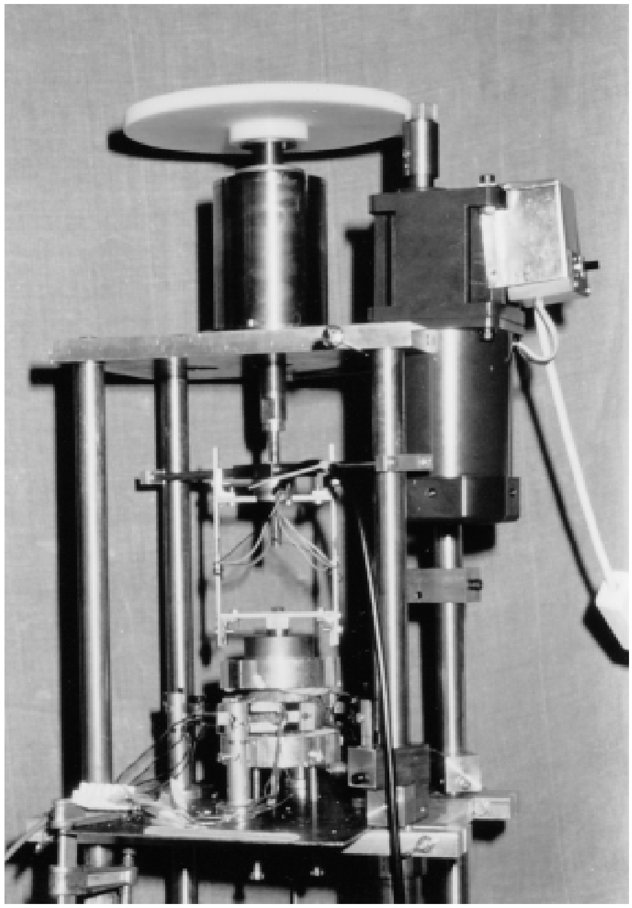

Fig. 1. Experimental set-up.

METHODS

Using the experimental set-up described above, loading of the specimens was increased stepwise up to a maximum load of 400 Newton. At this value, intervertebral discs began to show an exhaustion of elastic deformation and deformation cycles of the intervertebral discs were no longer reproducible beyond this value. We measured the correlation between axial deformation

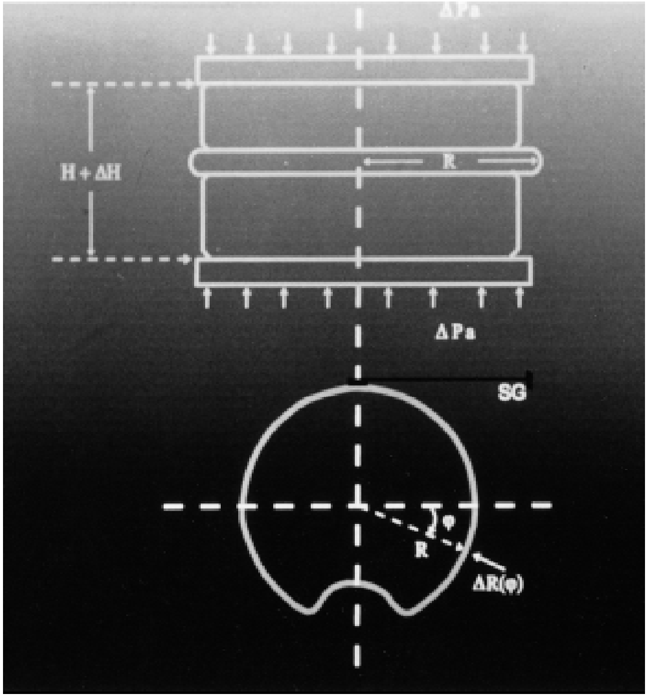

Fig. 2. $^{\Delta}$Pa = axial pressure. H+ M = axial decrease in height. R = Ext./Int. deviation.

and axial force as well as the deformation resulting from such axial loads (Fig. 2).

Deviation was examined under two standardized conditions: 1) deviation under constant decrease in height and 2) deformation resulting from a constant axial load of 400 Newton. Especially with the latter measurement stiffness of the intervertebral disc under a constant load was evaluated. Measurements were performed before and after laser ablation. In order to check the reproducibility of the data, several measurement cycles were performed at each experiment. The data were recorded via four sensors using the set-up described in Figure 3. This set-up permits recording of deviations between the positions three and four at a standarized access of the laser tube. After macroscopic inspection, the sensors were adjusted in such a way that they contacted the convex point of the intervertebral disc tangentially. This avoided rotatory deformations of the sensors. Moreover the mounting of a predeformation at the sensors allowed the recording of negative deformations (directed inwards). Because of the elasticity of the tissue each step of deformation was followed by a phase of relaxation.

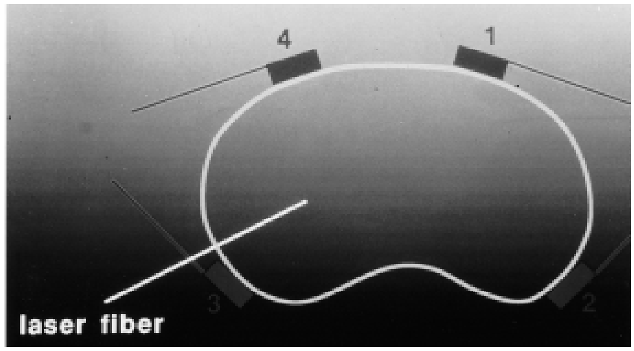

Fig. 3. Position of laser fiber and elongation measurement strips.

Statistics

Statistical evaluation of data was performed using Student's *t*-test. Significance was assumed at *P*-values of < 0.05.

RESULTS

Preoperative Disc Deformation

Preoperative measurement of decrease in axial height (external deviation/mm decrease in height) as well as predetermined load (external deviation/compression in Newton) gave equal and reproducible results. The probes 1–4 registered an external deviation of 0.25 ± 0.1, 0.22 ± 0.12, 0.12 ± 0.1, and 0.24 ± 1.6 mm, respectively, per mm decrease in axial height. The values for axial load showed similar results for the same probes 1–4: 0.59 ± 0.23, 0.48 ± 0.17, 0.27 ± 0.22, and 0.52 ± 0.26 μm per Newton respectively. A statistically significant difference was observed only for probe 3 positioned in the vicinity of the laser fiber. In comparison to the other probes it showed a significantly decreased external deviation (Table 1).

Postoperative Disc Deformation

Postoperative decrease in axial height was recorded for the probes 1–4 as follow: 0.28 ± 0.2, 0.38 ± 0.39, 0.22 ± 0.14, and 0.3 ± 0.2 mm, respectively. The corresponding values for axial load were: 0.9 ± 0.7, 1.23 ± 1.4, 0.74 ± 0.7, and 0.99 ± 1.0 μm per Newton, respectively. Postoperatively, the statistic differences between the different probe positions were insignificant (Table 2).

TABLE 1. Probes Comparison Preoperatively

External deviation in mm/mm decrease in height preoperatively				
	Probe 1	Probe 2	Probe 3	Probe 4
Probe 1	0.25 ± 0.11	0.22 ± 0.12 n.s.	0.12 ± 0.1 <0.01	0.23 ± 0.16 n.s.
Probe 2		0.22 ± 0.12	0.12 ± 0.1 <0.05	0.23 ± 0.16 n.s.
Probe 3			0.12 ± 0.1	0.23 ± 0.16 <0.05

External deviation in μm/compression in Newton preoperatively				
	Probe 1	Probe 2	Probe 3	Probe 4
Probe 1	0.6 ± 0.22	0.48 ± 0.17 n.s.	0.27 ± 0.22 <0.01	0.52 ± 0.26 n.s.
Probe 2		0.48 ± 0.17	0.27 ± 0.22 <0.01	0.52 ± 0.26 n.s.
Probe 3			0.27 ± 0.22	0.52 ± 0.26 <0.01

TABLE 2. Probes Comparison Postoperatively

External deviation in mm/mm decrease in height postoperatively				
	Probe 1	Probe 2	Probe 3	Probe 4
Probe 1	0.28 ± 0.18	0.38 ± 0.39 n.s.	0.22 ± 0.14 n.s.	0.30 ± 0.20 n.s.
Probe 2		0.38 ± 0.39	0.22 ± 0.14 n.s.	0.30 ± 0.20 n.s.
Probe 3			0.22 ± 0.14	0.30 ± 0.20 n.s.

External deviation in μm/compression in Newton postoperatively				
	Probe 1	Probe 2	Probe 3	Probe 4
Probe 1	0.87 ± 0.71	1.22 ± 1.42 n.s.	0.73 ± 0.69 n.s.	0.99 ± 1.00 n.s.
Probe 2		1.22 ± 1.42	0.73 ± 0.69 n.s.	0.99 ± 1.00 n.s.
Probe 3			0.73 ± 0.69	0.99 ± 1.00 n.s.

Comparison Between Preoperative and Postoperative Disc Deformation

No statistically significant differences for decrease in axial height and axial load were observed between the values recorded by the probes 1 and 4 positioned at the anterior parts of the anulus. Within the dorsal parts of the anulus a statistically significant increase in external deviation was recorded only for field three. This holds also for field two for the measurement after axial load. The somewhat higher probe values measured after decrease in axial height were without statistical significance (Table 3).

The ratio between load and axial deformation (dF/dh in N/μm) as a parameter for the degree of internal stiffness of the disc and therefore also as an indicator for deformability of the anulus exhibited a significantly lower postoperative value (0.44 ± 0.1 vs. 0.35 ± 0.8, $P < 0.01$).

Measurement of external deviation revealed an almost linear increase with increasing energy at a given decrease in axial height and at a given load (Figs. 4, 5). Stiffness of the intervertebral disc decreased with increasing energy ($P < 0.01$) (Fig. 6).

DISCUSSION

Studies published in this field up to now report on the influence of percutaneous semiinvasive discectomies on intradiscal pressure [16,17]. This holds true not only for laser nucleotomy but also for other semi-invasive procedures like chemonucleolysis and percutaneous nucleotomy [18–22]. The first measurements of intradiscal pressure were reported by Onik et al. [23]. These authors observed a significant decrease in intradiscal pressure and related this phenomenon mainly to the perforation of the anulus and, to a lesser degree, to the mechanical resection of the anulus. Similar results were reported by Hoppenfield [24] for percutaneous nucleotomy. The first measurements of intradiscal pressure following laser ablation were reported by Choy [16]. This author reported a significant reduction in intradiscal pressure using a Neodym:YAG laser at an energy of 1000 J [16]. An equally significant reduction in pressure was reported by Prodoehl [17] after application of a 2.1 Hol:YAG laser at an energy of 1200 J. The authors mentioned above related the efficiency of laser disc decompression to a pressure decrease in the dural sack or the nerve root, respectively, leading to a significant decrease in intradiscal pressure. However, up to now no report is available on the effect of intradiscal pressure on the outer circumference of the intervertebral disc. As changes in the dorsal parts of the outer circumference of the intervertebral disc are responsible for compression of the dural sack and the nerve root, we devoted special atten-

TABLE 3. Decrease in Axial Height

External deviation in mm/mm decrease in height		Probe 1	Probe 2	Probe 3	Probe 4
preoperative		0.25 ± 0.1	0.22 ± 0.12	0.12 ± 0.1	0.24 ± 1.6
P value		n.s.	n.s.	<0.05	n.s.
postoperative		0.28 ± 0.2	0.38 ± 0.39	0.22 ± 0.14	0.3 ± 0.2
External deviation in μm/compression in Newton	Stiffness F (N/μm)	Probe 1	Probe 2	Probe 3	Probe 4
preoperative	0.44 ± 0.1	0.59 ± 0.23	0.48 ± 0.17	0.27 ± 0.22	0.52 ± 0.26
P value	<0.01	n.s.	<0.05	<0.05	n.s.
postoperative	0.35 ± 0.08	0.9 ± 0.7	1.23 ± 1.4	0.74 ± 0.7	0.99 ± 1.0

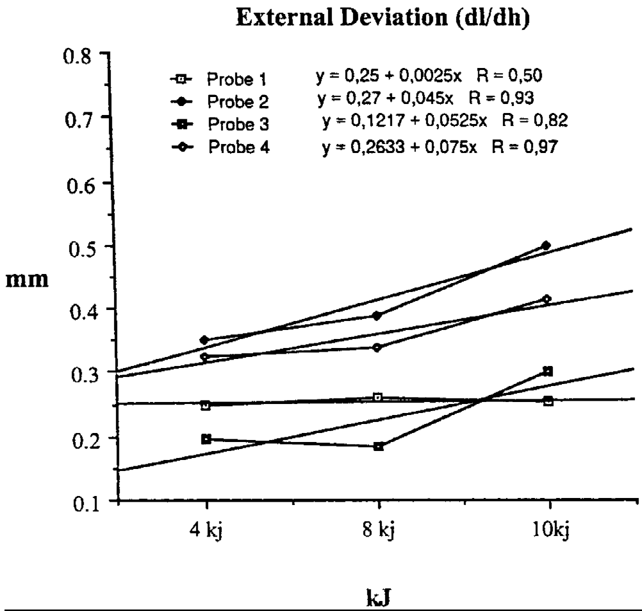

Fig. 4. Increase of external deviation with increase of energy per mm decrease of height.

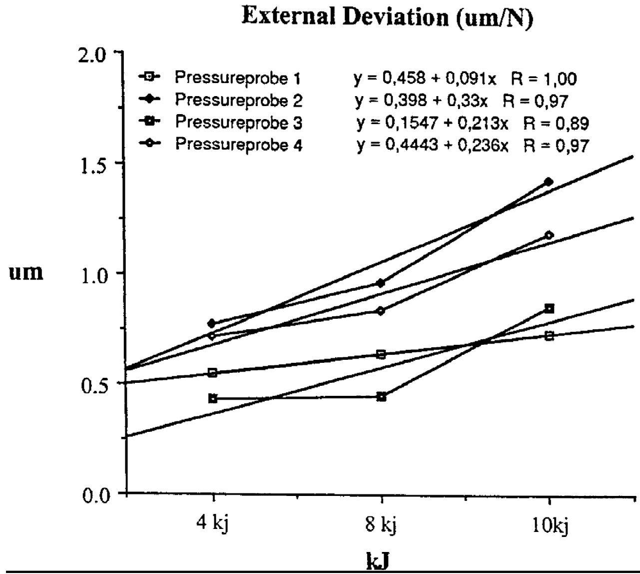

Fig. 5. Increase of external deviation with increase of energy per Newton.

tion to the measurement of the dorsal external deviation before and after nucleus decompression of the nucleus. Moreover, we measured the anterior parts of the intervertebral disc in order to evaluate pressure distribution for the complete cross-section.

In contrast to the single fiber technique of laser disc decompression published by the majority of authors [1–5, 9–14, 17] we used the Clarus techique for this experiment. This technique requires a constant lavage of the fiber tip. It might be argued that the saline lavage could increase the volume of the hydrophilic nucleus. This may occur in the initial part of the procedure. After ablation of some parts of the anulus a cavity is created in the disc allowing extension of the hydrophilic nucleus without increasing the intradiscal pressure. Furthermore, constant suction provided during the whole laser procedure allowed continuous removal of vaporized nucleus material together with fluid of the lavage from the intradiscal space.

Preoperative pressure measurements mainly exhibited a small external deviation within the area of puncture. These findings correlate with results reported by Onik [23], who allotted considerable importance to the fenestration of the anulus. Therefore, ipsilateral puncture of the intervertebral disc is recommendable for treatment of slipped discs. Following laser decompression balanced pressure conditions were observed within all the areas measured. This finding might indicate balanced pressure conditions within the total discal space after laser decompression of the nucleus.

However, the main aim of this investigation was to compare preoperative and postoperative

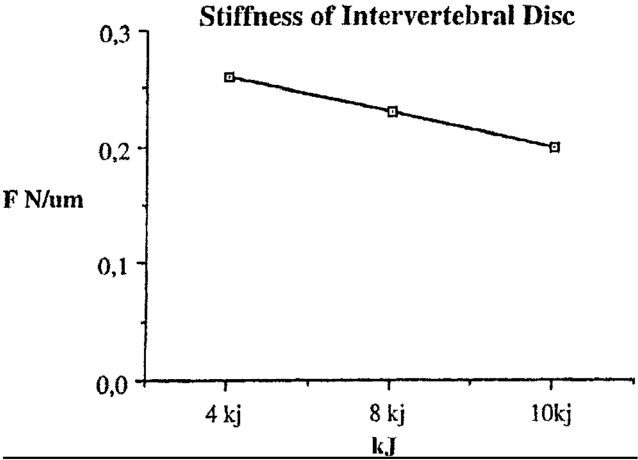

Fig. 6. Decrease of stiffness negatively correlating with increasing energy.

pressure distributions. We want to stress the fact that our investigation was carried out on healthy discs having no defect of the anulus, whereas disc protrusion is caused by a reduced resistance of the anulus. Our measurements exhibited an increase in deviation, mainly in the dorsolateral portions of the discs whereas the ventral portions remained almost unchanged. These results correspond to the anatomical/physiologic and pathologic/clinical findings of the localization of slipped discs. The almost exclusively dorsal prolapses might be explained by lordosis of the lumbar spine but also by the stronger anterior structures, especially the strong anterior longitudinal band. Despite the repeatedly reported reduction in intradiscal pressure and the connected decrease in pressure in the dorsal disc and the adjacent structures, we found an increased dorsolateral deviation of the disc. These obviously contradictory results might be explained on the one hand by a significant decrease in stiffness of the dorsal portions of the disc following laser nucleotomy and on the other hand by an intact anulus ring. Moreover, we want to point out that the maximum increase in disc deviation was 500 μm. Though an originally stiff disc passes peak pressures mainly via the prolapse, we have to assume equal pressure distribution over the total disc in our case due to the significant reduction in stiffness of the dorsal portions of the discs. Our observation of equal pressure distribution within the total circumference confirms this assumption. Therefore it might be concluded that a pressure equally distributed all over the disc reduces peak pressure loads within the prolapse region. Under an axial load of 400 Newton we observed an external deviation of 200–500 μm of discs with equal pressure distribution. Such a limited deviation is unlikely to exert a compressive effect on neural structures. In diseased discs, however, load pressure concentrated on the prolapse may be expected to cause a considerably higher external deviation in this weakened area. In pathologic discs it might be expected that by reducing the intradiscal pressure and by distributing the remaining pressure over the total circumference of the anulus, peak pressure in the prolapse region can be considerably reduced. Moreover, our measurements showed an almost linear decrease in disc stiffness with increasing total energy. This almost linear negative correlation allows us to assume that there will be a good correlation between total energy applied (up to 10 kJ) and therapeutic effect. In our series of experiments we observed an increasing number of anulus perforations at the contralateral portions of the discs at loads exceeding 10 kJ resulting in destruction of the closed pressure system and rendering further exact measurements impossible.

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